PM$_{10}$ Chemical Characteristics in a Background Site at the Universidad Libre Bogotá

Laura X. Martinez, Andrés F. Rodriguez, Ruth A. Catacoli

Abstract—One of the most important factors for air pollution is that the concentrations of PM$_{10}$ maintain a constant trend, with the exception of some places where that frequently surpasses the allowed ranges established by Colombian legislation. The community that surrounds the Universidad Libre Bogotá is inhabited by a considerable number of students and workers, all of whom are possibly being exposed to PM$_{10}$ for long periods of time while on campus. Thus, the chemical characterization of PM$_{10}$ found in the ambient air at the Universidad Libre Bogotá was identified as a problem. A Hi-Vol sampler and EPA Test Method 5 were used to determine if the quality of air is adequate for the human respiratory system. Additionally, quartz fiber filters were utilized during sampling. Samples were taken three days a week during a dry period throughout the months of November and December 2015. The gravimetric analysis method was used to determine PM$_{10}$ concentrations. The chemical characterization includes non-conventional carcinogenic pollutants. Atomic absorption spectrophotometry (AAS) was used for the determination of metals and VOCs were analyzed using the FTIR (Fourier transform infrared spectroscopy) method. In this way, concentrations of PM$_{10}$ ranging from values of 13 μg/m$^3$ to 66 μg/m$^3$ were obtained; these values were below standard conditions. This evidence concludes that the PM$_{10}$ concentrations during an exposure period of 24 hours are lower than the values established by Colombian law, Resolution 610 of 2010; however, when comparing these with the limits set by the World Health Organization (WHO), these concentrations could possibly exceed permissible levels.

Keywords—Air quality, atomic absorption spectrophotometry, Fourier transform infrared spectroscopy, particulate matter.

I. INTRODUCTION

Air pollution is defined as the existence of high concentrations of substances in the air over a period of time, due to anthropic activities or natural processes, which could cause harmful effects to the environment and the health of people and living beings [1]. Found within the relevant atmospheric pollutants are total suspended particulates (PST), particulate matter (PM$_{10}$ and PM$_{2.5}$), sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), tropospheric ozone (O$_3$), carbon monoxide, Lead and its Compounds, mercury, benzene, cadmium, toluene and vanadium [2]. Thus, the particulate matter is found within the main pollutants. These particles are bodies of matter that exist in liquid or gas phases and accumulate in different shapes and sizes (0 - 100 μm). Furthermore, it has an aerodynamic diameter, equal to or less than 10 μm, being of great importance in urban pollution, due to its negative influence on the pulmonary alveoli, affecting society’s quality of life [3].

Specifically, air quality refers to the state in which air pollution is found, namely, it is estimated as an air pollution indicator to define how suitable the air is to be respired [4]. From this view point, Bogotá has relatively acceptable pollution levels with respect to CO, NOx and SOx, however, the problem is directly related to photochemical smog and particulate matter [5].

In the case of Universidad Libre Bogotá, there is a community of students and workers who could be exposed to the risks generated by PM$_{10}$ levels present on the campus for long periods of time. In this way, the characterization of particulate matter has been identified as a problem in a background site at the Universidad Libre, using a high-volume sampler, which allowed the daily pollutant concentration to be determined, taking into consideration the importance of the community’s wellbeing and quality of life regarding the contact with this material.

II. MATERIALS AND METHODS

Initially, a TSP and PM$_{10}$ high volume sampler were used, which are approved by EPA method 5 for total PM mass. Secondly, the TSP and PM$_{10}$ HI-VOL were installed in a background site close to the Engineering Faculty air labs. In addition, 10" x 8” quartz fiber filters were used.

The sampling process was carried out between November and December 2015, collecting a total of 11 samples. Each filter remained on site for 24 hours +/- 1 hour in the sampling process which took place on Mondays, Wednesdays and Fridays.

Based on the samples collected by the filters, the concentrations of PM$_{10}$ were then determined using the gravimetric analysis method. With respect to chemical characterization, the parameters were the nonconventional pollutants with carcinogenic effects, such as Benzene, Lead and its compounds, Cadmium, Inorganic Mercury, Toluene and Vanadium, established by the Colombian Resolution 610 of 2010, considering it was necessary to implement the filter’s extraction process for its reading. The procedure was performed using an extractive solution composed of 63% nitric acid (HNO$_3$) and 37% hydrochloric acid (HCl), to which an 8” x 1” filter fragment was added. Subsequently, the obtained sample was introduced to a heating process using the
ultrasound technique, maintaining the water temperature at 60°C for six cycles of 30 minutes each [6].

Apart from that, an analytical study was carried out using the AAS method, determining the elements Vanadium (V), Lead (Pb), Inorganic Mercury (Hg) and Cadmium (Cd) that were individually present in the sample. The FTIR method was used to identify the volatile organic compounds.

Additionally, a comparative analysis was carried out using IDW maps that showed the distributions of PM\textsubscript{10} concentration in the city. Information obtained from the Bogotá Air Quality Monitoring Network (RMCAB) was also used, demonstrating the similarities between the sampled concentrations and those consulted theoretically.

Lastly, using particulate matter and unconventional pollutant concentrations, the harmful effects on the health of the community surrounding the university were identified, marking a comparison with the levels set in the guidelines for air quality according to the exposure degree established by the WHO.

### III. RESULTS AND DISCUSSION

#### A. PM\textsubscript{10} Concentrations

Table I presents the results obtained during the sampling in November and December 2015, displaying the respective flow rate and concentration calculations in actual conditions (Q\textsubscript{a} and Ca) and standard conditions (Q\textsubscript{std} and C\textsubscript{std}), taking into consideration the permissible limits established by Resolution 610 of 2010 and the WHO, in order to make a comparison, and determine their fulfillment in both cases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Q\textsubscript{a} (m\textsuperscript{3}/min)</th>
<th>Q\textsubscript{std} (m\textsuperscript{3}/min)</th>
<th>Ca (µg/m\textsuperscript{3})</th>
<th>C\textsubscript{std} (µg/m\textsuperscript{3})</th>
<th>Res. 610/2010 (µg/m\textsuperscript{3})</th>
<th>WHO (µg/m\textsuperscript{3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.187</td>
<td>1.4002</td>
<td>21</td>
<td>18</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.187</td>
<td>1.4558</td>
<td>18</td>
<td>15</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.187</td>
<td>1.3826</td>
<td>15</td>
<td>13</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.187</td>
<td>1.4488</td>
<td>20</td>
<td>16</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.187</td>
<td>1.4906</td>
<td>20</td>
<td>16</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.187</td>
<td>1.6046</td>
<td>42</td>
<td>31</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.187</td>
<td>1.5084</td>
<td>20</td>
<td>15</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1.187</td>
<td>1.5400</td>
<td>26</td>
<td>20</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1.187</td>
<td>1.4954</td>
<td>36</td>
<td>28</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.187</td>
<td>1.4368</td>
<td>80</td>
<td>66</td>
<td>100</td>
<td>50</td>
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<td>11</td>
<td>1.187</td>
<td>1.4853</td>
<td>22</td>
<td>17</td>
<td>100</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 shows the behavior of particulate matter (PM\textsubscript{10}) concentration during the respective sampling, where the analyses of 11 samples were performed, suppressing sample number 10 present in Table I, since this one has an outstanding value with respect to the rest, being considered an atypical data due to a burning process carried out the same day in an area near the sampling point. In this context, the maximum concentration value is 31 g/m\textsuperscript{3} and the minimum value is 13 g/m\textsuperscript{3}, corresponding to sample 6 and sample 3, respectively.

In this context, the concentrations found in the sampling period are within the permissible limits established by Colombian legislation in resolution 610 of 2010 and the WHO, which both exhibit a maximum PM\textsubscript{10} concentration level of 100 g/m\textsuperscript{3} and 50 g/m\textsuperscript{3} in a 24 hour exposure period [7], [8]. Table III shows the maximum permissible PM\textsubscript{10} levels.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Maximum permissible level Res. 610/2010 (µg/m\textsuperscript{3})</th>
<th>Maximum permissible level WHO (µg/m\textsuperscript{3})</th>
<th>Exposure time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM\textsubscript{10}</td>
<td>50</td>
<td>20</td>
<td>Annual</td>
</tr>
<tr>
<td>Lead</td>
<td>100</td>
<td>50</td>
<td>24 Hours</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.5</td>
<td>-</td>
<td>Annual</td>
</tr>
<tr>
<td>Inorganic Mercury</td>
<td>5x10\textsuperscript{-3}</td>
<td>-</td>
<td>Annual</td>
</tr>
<tr>
<td>Vanadium</td>
<td>1</td>
<td>-</td>
<td>24 Hours</td>
</tr>
</tbody>
</table>

Fig. 2 presents the concentration data taken during sampling and those obtained through records from the RMCAB and the IDRD station. It is observed that the concentrations consulted in the station, as well as those obtained in the sampling, do not exceed the maximum permissible limits indicated in the resolution. Likewise, the station and sampling point...
concentrations follow a similar tendency; however, IDRD concentrations are higher than those known from the sampling. On the other hand, it is important to emphasize that station selection was made with comparative purposes in mind, considering that the sampling point is in a background area that had similar characteristics to the Universidad Libre. Likewise, Fig. 3 shows the correlation between the concentrations of the sampling point and the IDRD station, making it evident that the values present a significant difference since their $R^2$ is 0.3186, with 1 being the optimal value in the analysis.

The IDW maps contain a total of five concentration ranges, each having a specific color assigned. Fig. 4 corresponds to sample 3 and sample 4, verifying that the concentration calculated for these days coincides with the IDW map ranges. This also takes into account the fact that the same case is presented for the rest of the concentrations found in the sampling process. This confirms that the IDW methodology is an efficient tool that can be used to identify the approximate concentration of a specific zone, allowing the ability to compare other studies.

C. Presence of Heavy Metals
In order to identify the presence of heavy metals in the samples, the respective extraction process was implemented using hot acids. The analyses were performed using the atomic absorption spectrophotometer (EAA), where concentrations were found to be below the value established by Colombian air quality legislation (Res. 610 / 2010), displayed in Table IV.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cd (µg/m³)</th>
<th>Pb (µg/m³)</th>
<th>Hg (µg/m³)</th>
<th>V (µg/m³)</th>
<th>Cd (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>6</td>
<td>31</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
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<tr>
<td>8</td>
<td>20</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
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<td>&lt;0.028</td>
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<tr>
<td>9</td>
<td>28</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>10</td>
<td>66</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
<td>&lt;0.45</td>
<td>&lt;4.2</td>
<td>&lt;1.9</td>
<td>&lt;0.028</td>
</tr>
</tbody>
</table>

D. FTIR Analysis
In order to conduct the FTIR analysis, an infrared spectrum was used, as well as a white filter, and pure forms of benzene and toluene. This comparative process helped identify and conclude if the PM$_{10}$ samples showed traces of benzene and toluene.

Fig. 4 shows the sample 1 spectrum and the white filter spectrum. The graph allows to determine that the peaks located between the 993 cm$^{-1}$ - 1246 cm$^{-1}$ and 412 cm$^{-1}$ - 514 cm$^{-1}$, demonstrate the possible existence of filter (without sample) components, which explains the reason why they are not taken into account when performing the Spectrum analysis. It is important to notice that these peaks are present in all samples.
Figs. 6-13 allow to infer that the samples obtained do not contain toluene traces, due to the absence of stress peaks in the ranges of 1496 cm\(^{-1}\) - 1605 cm\(^{-1}\) and 3000 cm\(^{-1}\) - 3100 cm\(^{-1}\), in addition to a bending strip between 696 cm\(^{-1}\) and 729 cm\(^{-1}\) [10]. Therefore, it was established that the samples taken from the background site did not include any traces of toluene.
On the other hand, all samples, with the exception of sample 2 and sample 11, show a peak characterized by benzene in the 2280 cm\(^{-1}\) - 2380 cm\(^{-1}\) range, which allows to affirm that during the sampling period there were benzene traces which may have been generated by the combustion caused by vehicles used by the community surrounding the university.

IV. CONCLUSION

In conclusion, particulate matter (PM\(_{10}\)) concentrations, during an exposure period of 24 hours, are lower than the values established in Resolution 610 of 2010; however, the comparison of these values with the limits determined by WHO allows to infer that the concentrations could exceed the levels stipulated by this organization.
It can also be shown that the limits established by
Colombian legislation are double the amounts of those
established by the WHO, which shows that air quality
management could be improved if international standards
were followed, allowing to establish strict limits on the same
exposure times, creating a necessary change in the country’s
stationary sources.

From analyzing PM$_{10}$ to analyzing heavy metal
concentrations, it is concluded that the air quality present at
Universidad Libre Bogotá does not present a risk to the
population’s well-being, since the values do not exceed the
maximum permissible limits of Resolution 610 of 2010 and
those established by WHO. Likewise, the spectrums obtained
from the FTIR exhibit an absence of toluene in the analyzed
samples. On the other hand, the spectrum showed that there is
a possibility of finding traces of benzene, which may have
possibly been a product of the vehicles used around the
university. The majority of these vehicles use fossil fuels;
therefore, a gas chromatographic analysis would determine the
amount of pollutant that is present, allowing for a comparison
to be made with the current Colombian legislation.

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